TID - 27200

ADVANCED THERMIONIC ENERGY CONVERSION

ERDA CONTRACT E(11-1)-2263
NASA CONTRACT NAS3-19861

JOINT HIGHLIGHTS AND STATUS REPORT

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TASK 1200 - BASIC CHARACTERIZATION

Structured Electrodes - **The theoretical model of the ignited-mode, diode converter which was described in the last monthly has been used this month to study the effects of structured electrodes on converter I-V characteristics. A preliminary study of these effects was reported in the March monthly. That study used a phenomenological description of the converter. The study has been continued with this more detailed model because it provides a more accurate description of converter phenomena.**

It was pointed out in the March monthly that extended-area emitters give an effective higher emission for the converter, but also introduce a greater electron backscatter. Therefore, I-V curves show enhanced output current, but with a slight loss in output voltage. Both effects are shown by the calculated characteristics in Fig. 1. These results confirm the previous calculations.

Increasing the area of the collector enhances collection of electrons at the collector versus the emitter. As was shown in the March monthly this gives an effective decrease in the arc drop V_d of

$$V_d = -\frac{kT_e}{e} \ln(A_C/A_E)$$

where T_e is the electron temperature and A_C and A_E are the areas of the collector and emitter respectively. The calculated effect is shown in Fig. 2. Again these latest results confirm the earlier calculations with the phenomenological model. By combining the emitter and collector effects, the increased emission is obtained without the increased arc drop, as shown in Fig. 3. It is important to note that this increase in converter current could be obtained also be lowering the emitter work function, but in that case there would be a corresponding output voltage loss due to the change in the contact potential difference.

The enhancement of electron collection at the collector versus the emitter can also be accomplished by lowering the electron reflection coefficient of the collector r_C with respect to that of the emitter r_E. The effective reduction of arc drop due to electrode reflectivity differences is equal to

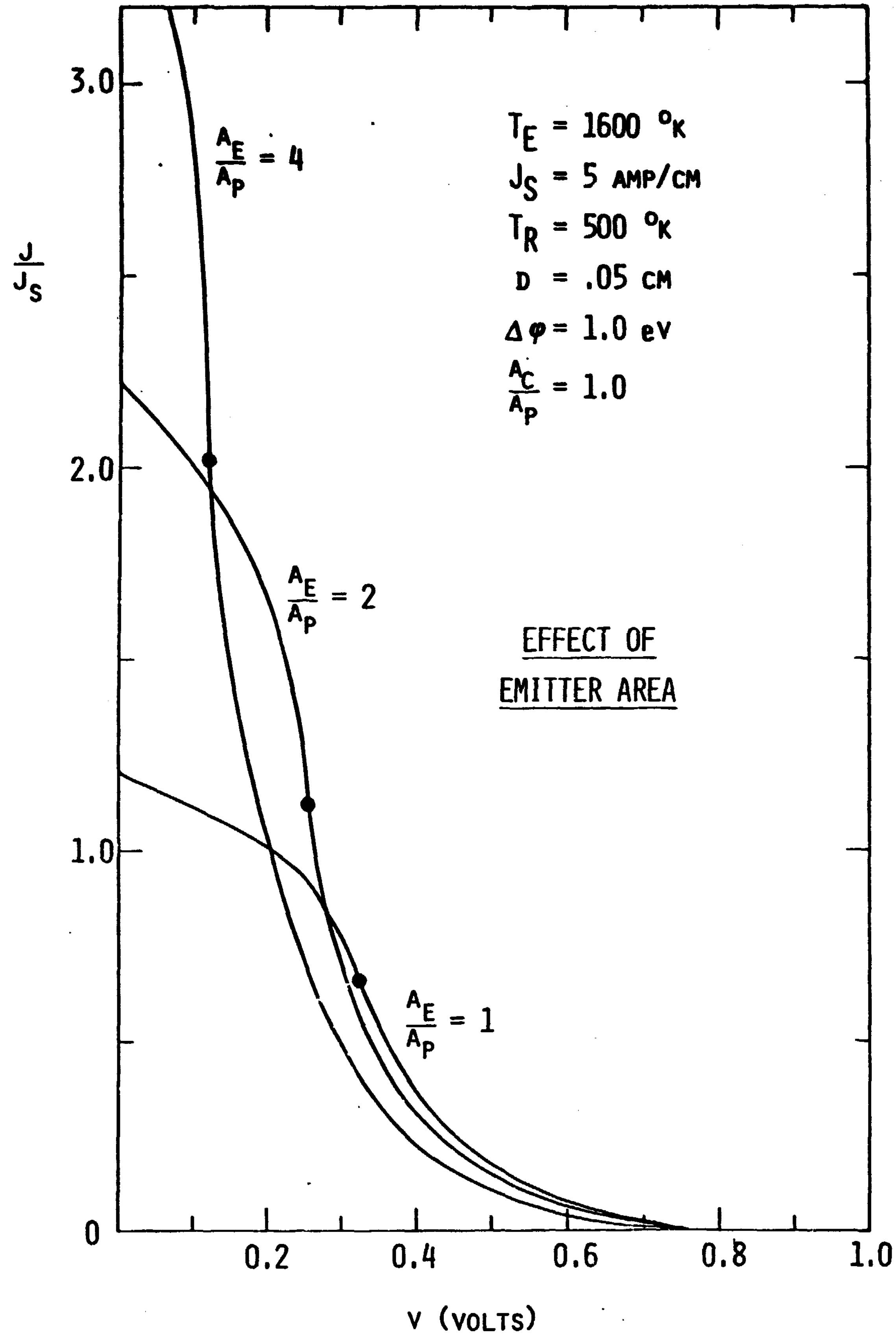

Fig. 1 Effect of Emitter Area on Converter I-V Characteristics (A_p = Electrode Projected Area)

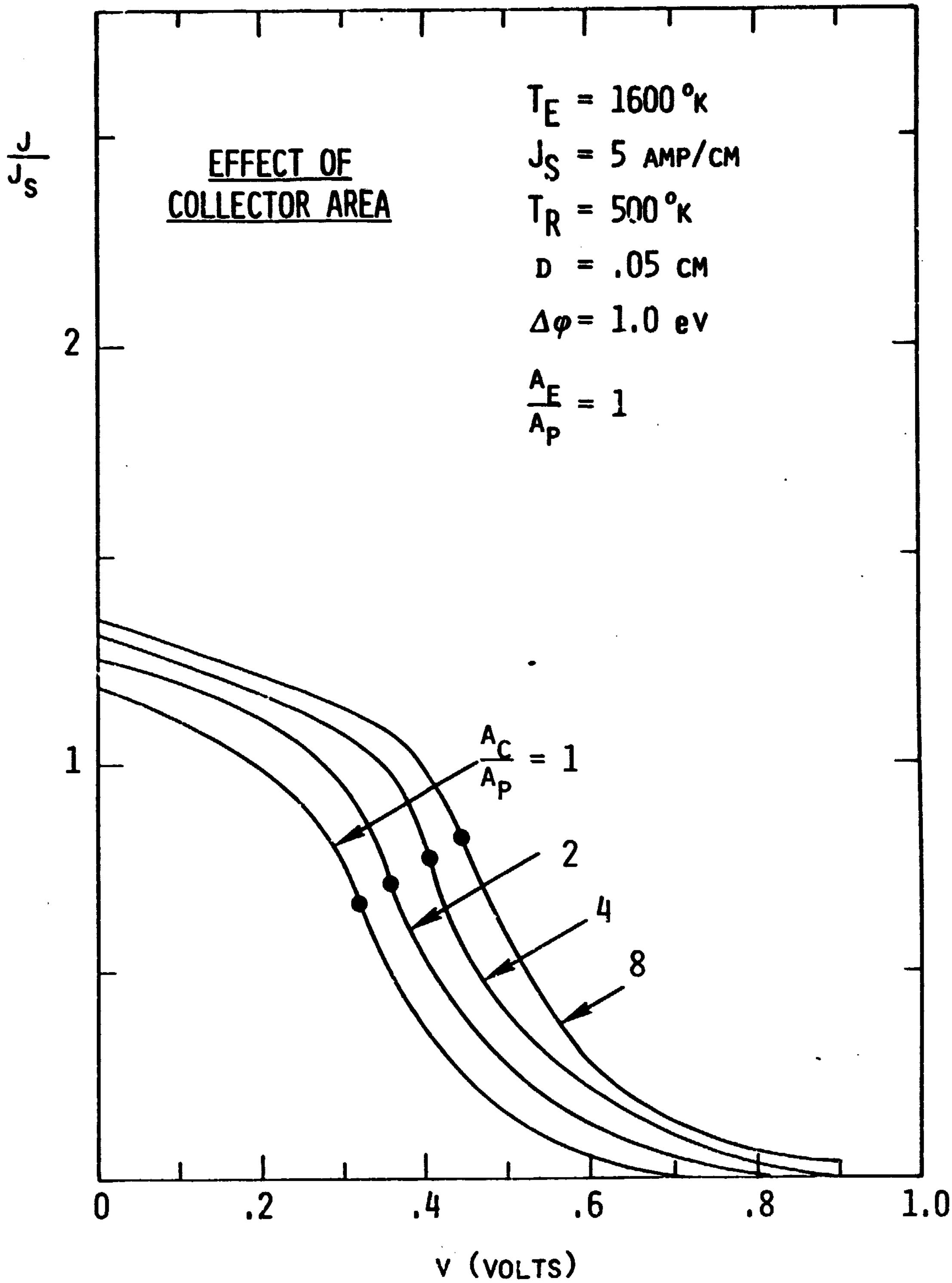

Fig. 2 Effect of Collector Area on Converter I-V Characteristics (A_p = Electrode Projection Area)

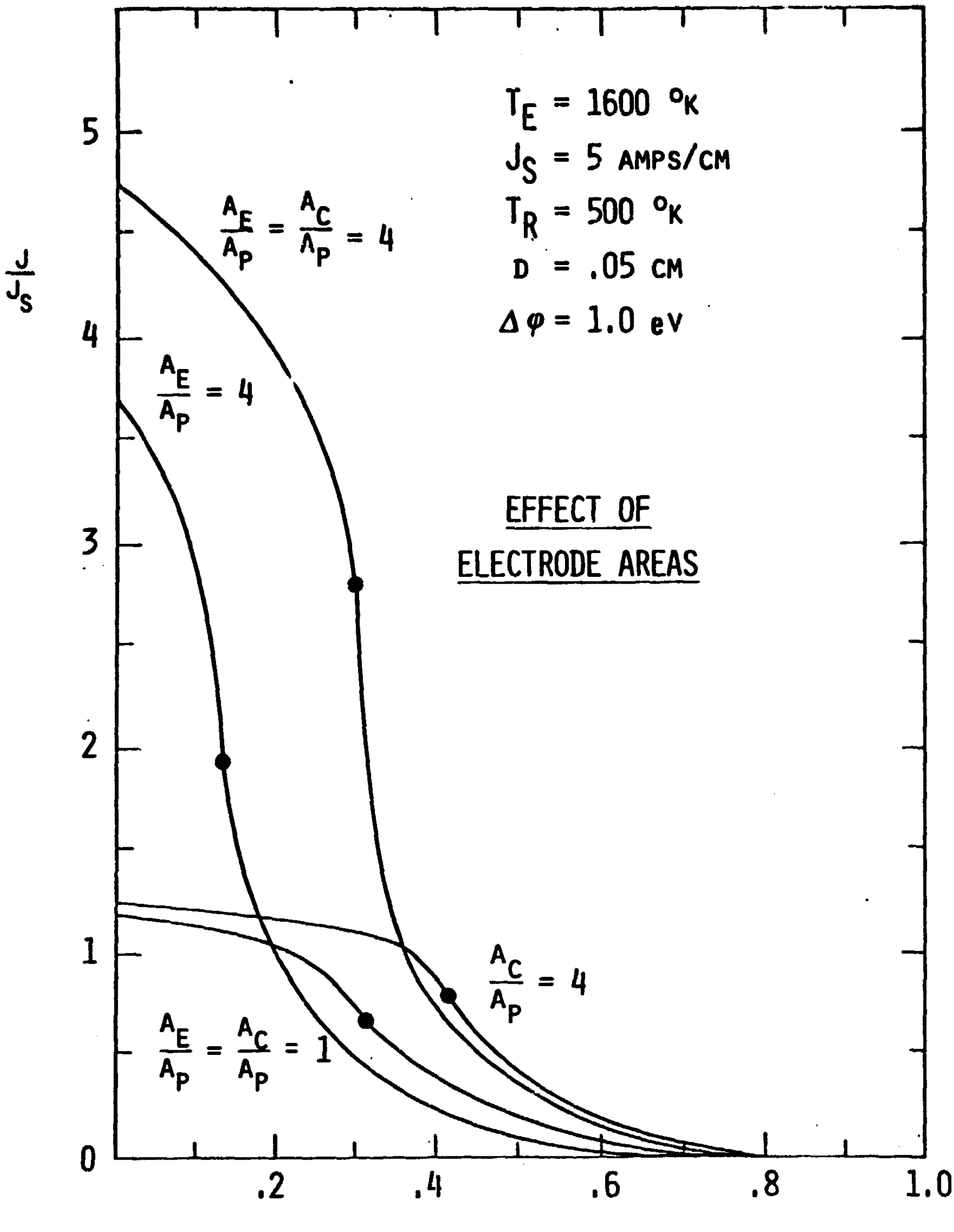

Fig. 3 Effect of Electrode Areas on Converter I-J Characteristics (A_p = Electrode Projection Area)

$$V_d = -\frac{kT_e}{e}\ \ln(1 - r_C)/(1 - r_E)$$

The effects on converter performance resulting from changes in the emitter and collector reflectivities are shown in Fig. 4 and 5 respectively. It is evident from these figures that significant performance improvement can be obtained by raising r_E and lowering r_C. Ways to accomplish this in practice are being explored.

All of the above extended area and reflectivity effects are important to converter performance and are being studied experimentally in the present program.

TASK 1300 - ADVANCED CONVERTER DEMONSTRATION

1320 - Demountable Converters

Structured Electrodes - The structured electrodes described in the March and April reports have been prepared. Fig. 6 shows, for example, two electrodes for the demountable converter. Surface grooves were cut by EDM machining of a platinum-coated molybdenum electrode. The grooves are 30 mils wide and 50 mils deep. Fig. 7 shows a scanning electron enlargement of an electrode surface of CVD Rhenium. The scale for this structure is shown in the figure. The electrode of Figs. 6 and 7 represent the extremes for two orders of magnitude in scale spread. Structured electrode effects through this full scale range are being studied in the present program. These figures show two examples of how the effective area of the electrode can be increased above the electrode projected area.

1330 - Fixed Configuration Converter

Some slight modifications were made in the fixed configuration test stand to better control parameters in the cylindrical converter tests.

The cylindrical diode with a platinum emitter was operated for over one hundred hours. Some slight improvements in performance were observed.

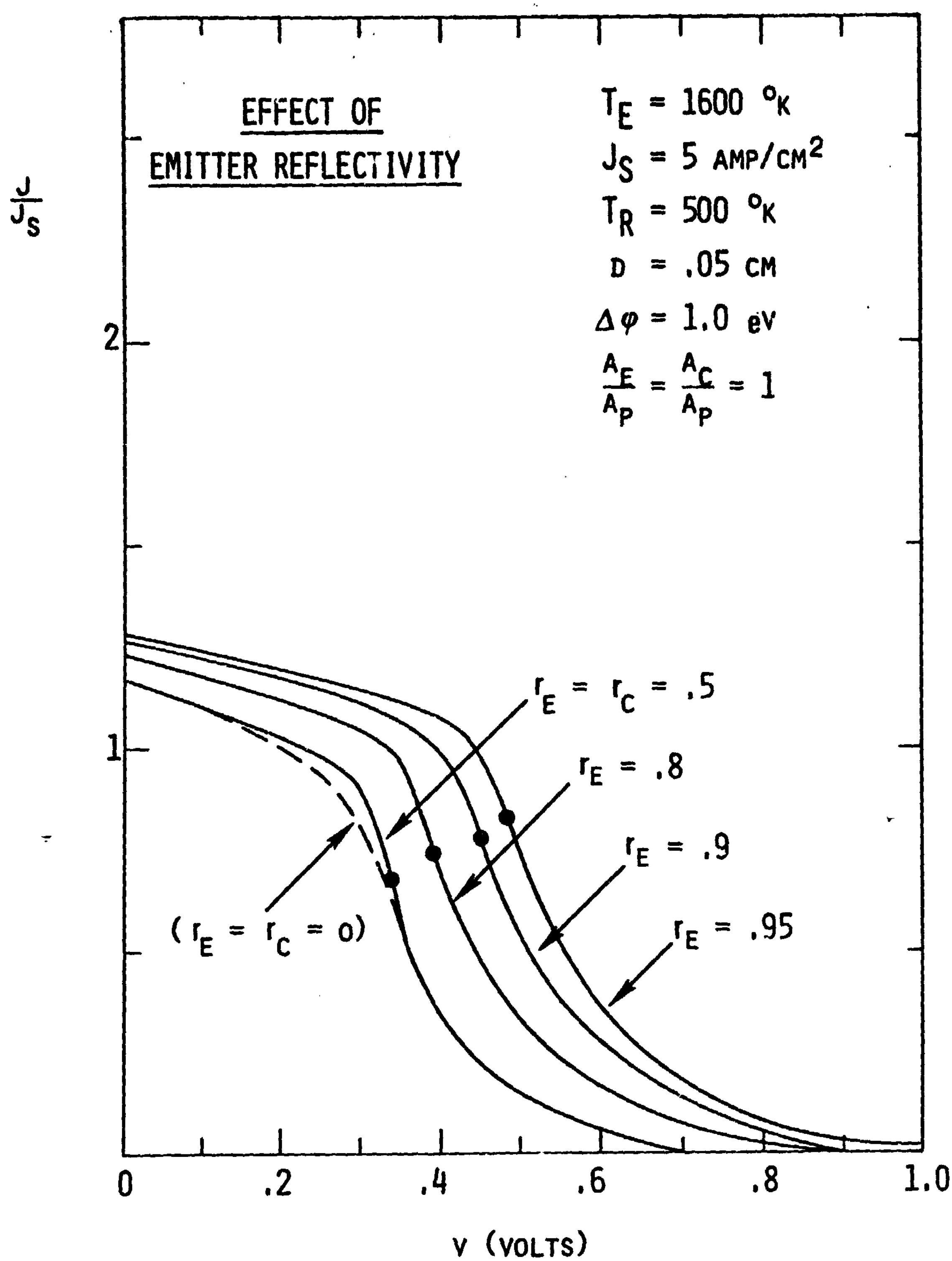

Fig. 4 Effect of Emitter Electron-Reflectivity on Converter I-V Characteristics

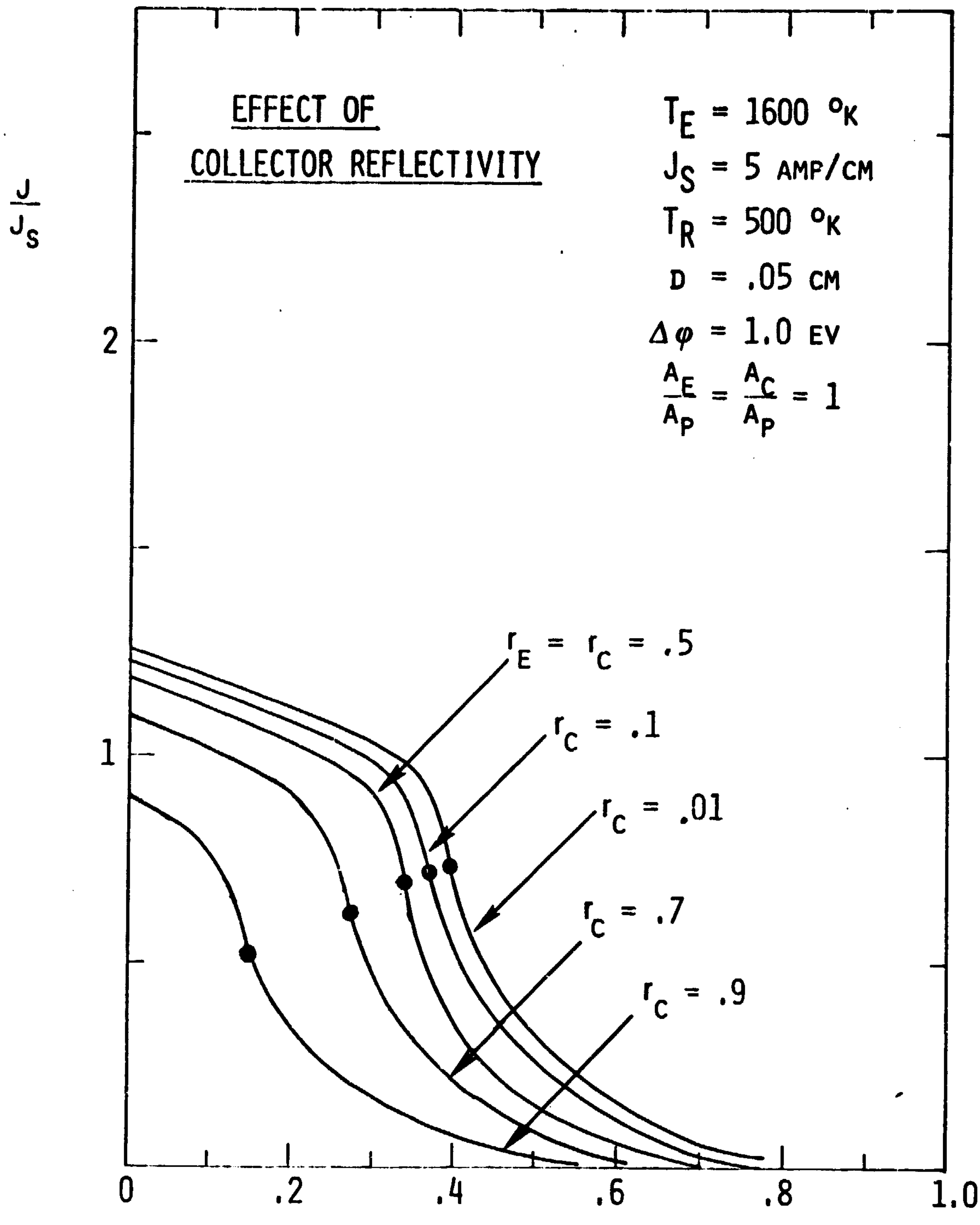

Fig. 5 Effect of Collector Electron-Reflectivity on Converter I-V Characteristics

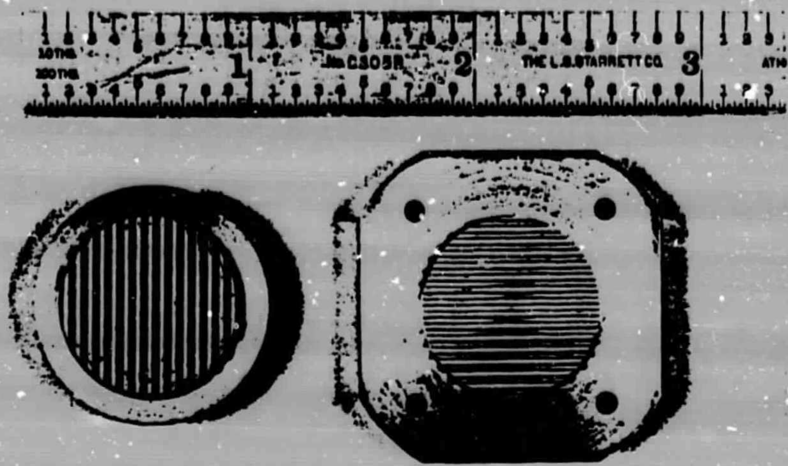

Fig. 6 EDM Platinum Electrodes

1 mil

Fig. 7 CVD Rhenium Electrodes

TASK 3100 - BASIC EXPERIMENTAL INVESTIGATION

Enhancement Distribution - The research converter for studying auxiliary-ion-source triodes was put into operation. This converter is especially useful for studying enhancement distribution and magnetic effects. The enhancement distribution for operation as a plasmatron was obtained using the series of probes mounted in the collector. A series of I-V curves for these probes are shown in Fig. 8. The upper I-V curve in each photo is the converter I-V curve; the lower (at a different scale factor) is the probe characteristic. The positions of the probes for this sequence of I-V characteristics is shown by Fig. 9. Probe 4 is in the plane of the auxiliary electrode. The enhancement distribution is a function of the width of the ion generation region, the extent of spreading of the ions along the interelectrode gap and the effect of these ions on the converter current density. The net effect is the observed current distribution, an example of which is shown in Fig. 10. The positions for the probe current measurements are shown on this figure by the scaled sectional view of the interelectrode space. No current was observed at the central probe (directly under the auxiliary electrode), but current density in that region was estimated from the total integrated current of the device. Except for the inferred rapid drop-off close to the auxiliary electrode, the current density fall is about a factor of 2 for every 2 electrode spacings away from the auxiliary electrode. The electron mean free path for thermal electrons in this case is also the same order of magnitude as the interelectrode spacing.

Magnetic Effects - Because the plasmatron is inherently a low pressure device, it is more sensitive to magnetic cut-off than the usual arc-mode converter. The magnetic cut-off for the plasmatron has been measured with the cylindrical research converter. Because of the double ended emitter in this device, current can be passed along the emitter to generate an azimuthal magnetic field in the interelectrode space. The observed effect is shown in Fig. 11 where total converter current is plotted versus magnetic flux density. Reduction to 20% of full current occurs at 70 gauss, which corresponds to about 200 amps of axial current. The circular path of an electron with average thermal velocity in a magnetic field would have a diameter equal to the spacing at only 10-20 gauss. That the cut-off is more sluggish than this is probably due to a small amount of interelectrode scattering. Even so, for large advanced mode devices with large

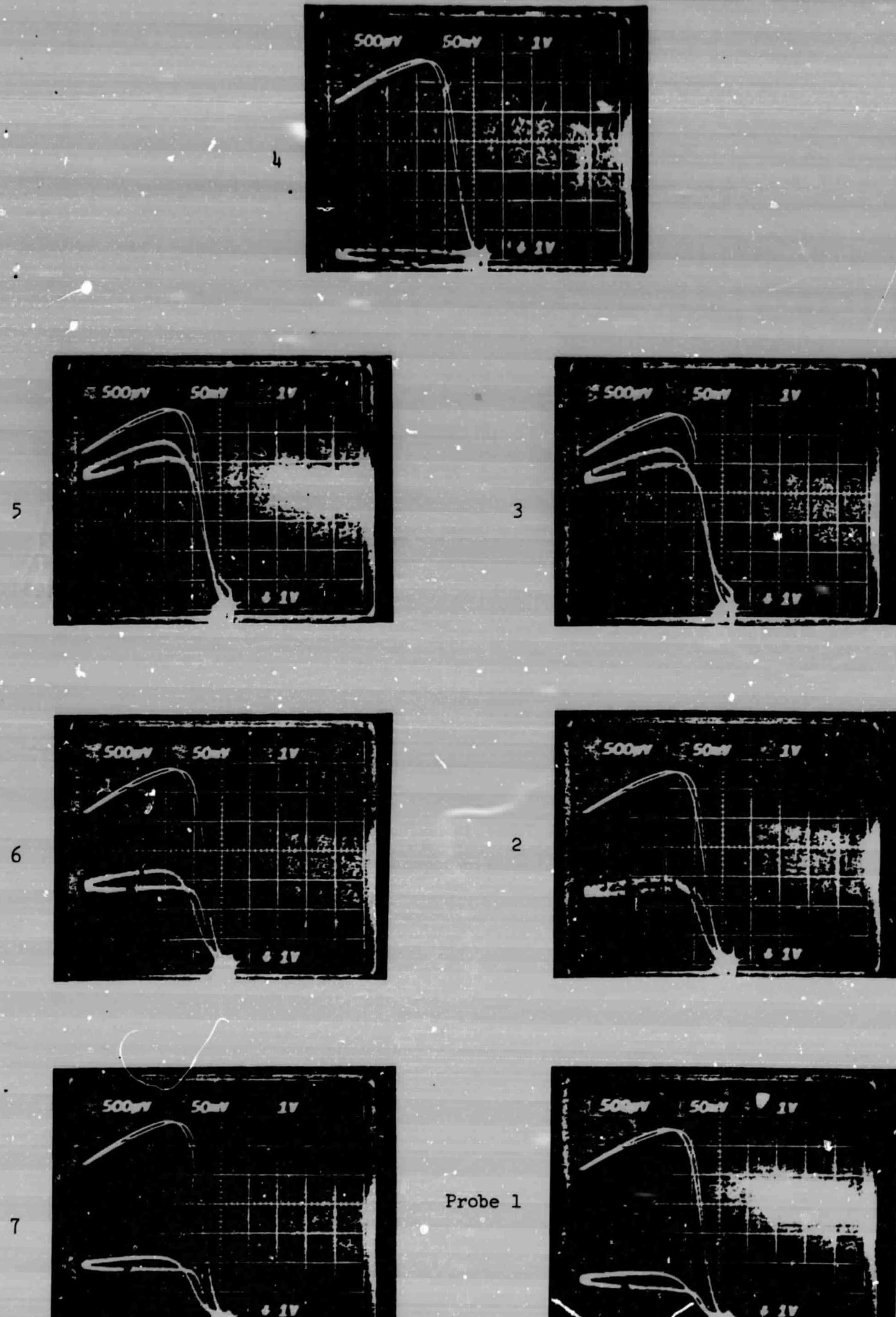

Fig. 8 Converter and Probe Characteristic for the Cylindrical Plasmatron

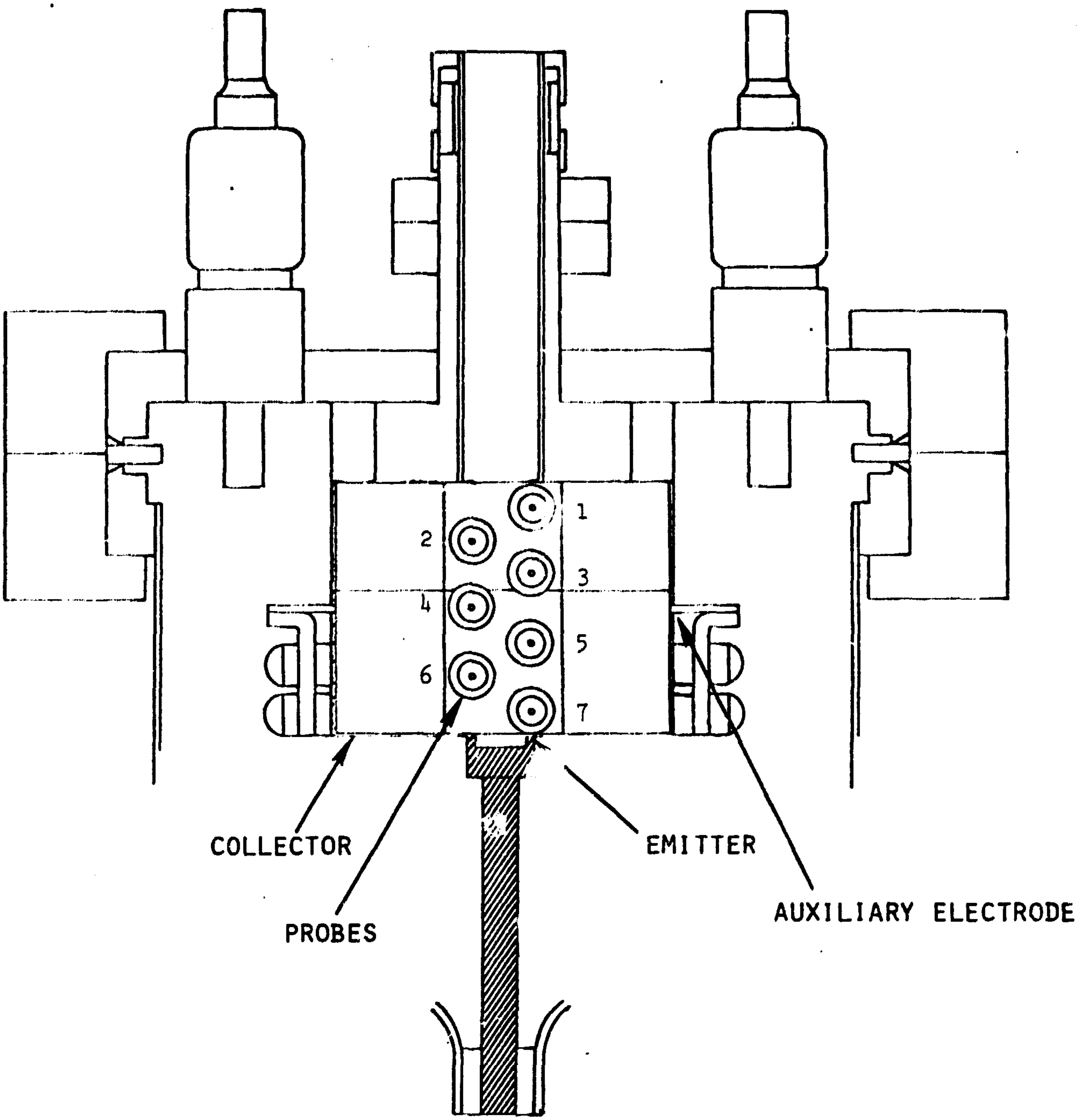

Fig. 9 Probe Positions in the Cylindrical Plasmatron

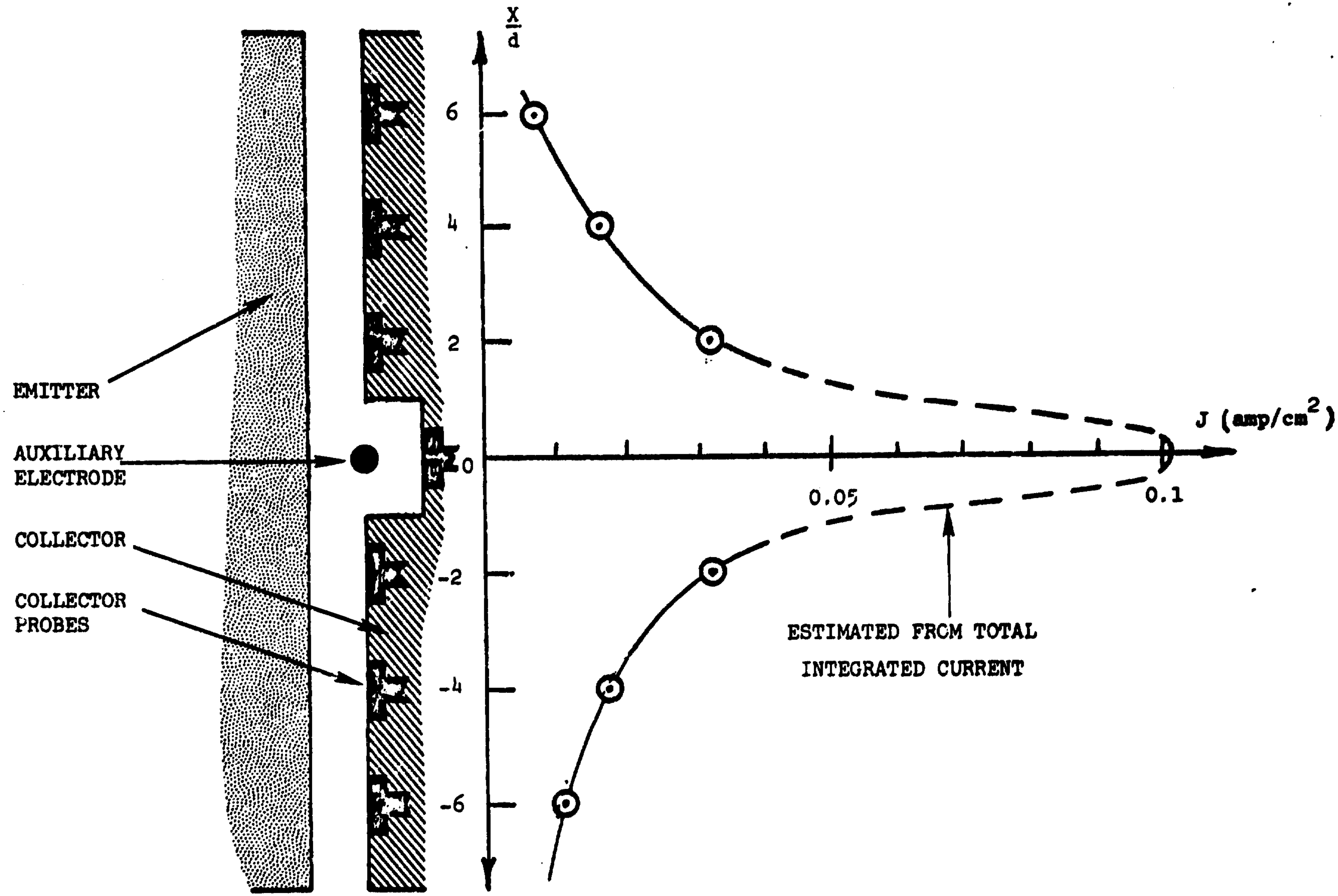

Fig. 10 Enhancement Distribution in the Cylindrical Plasmatron

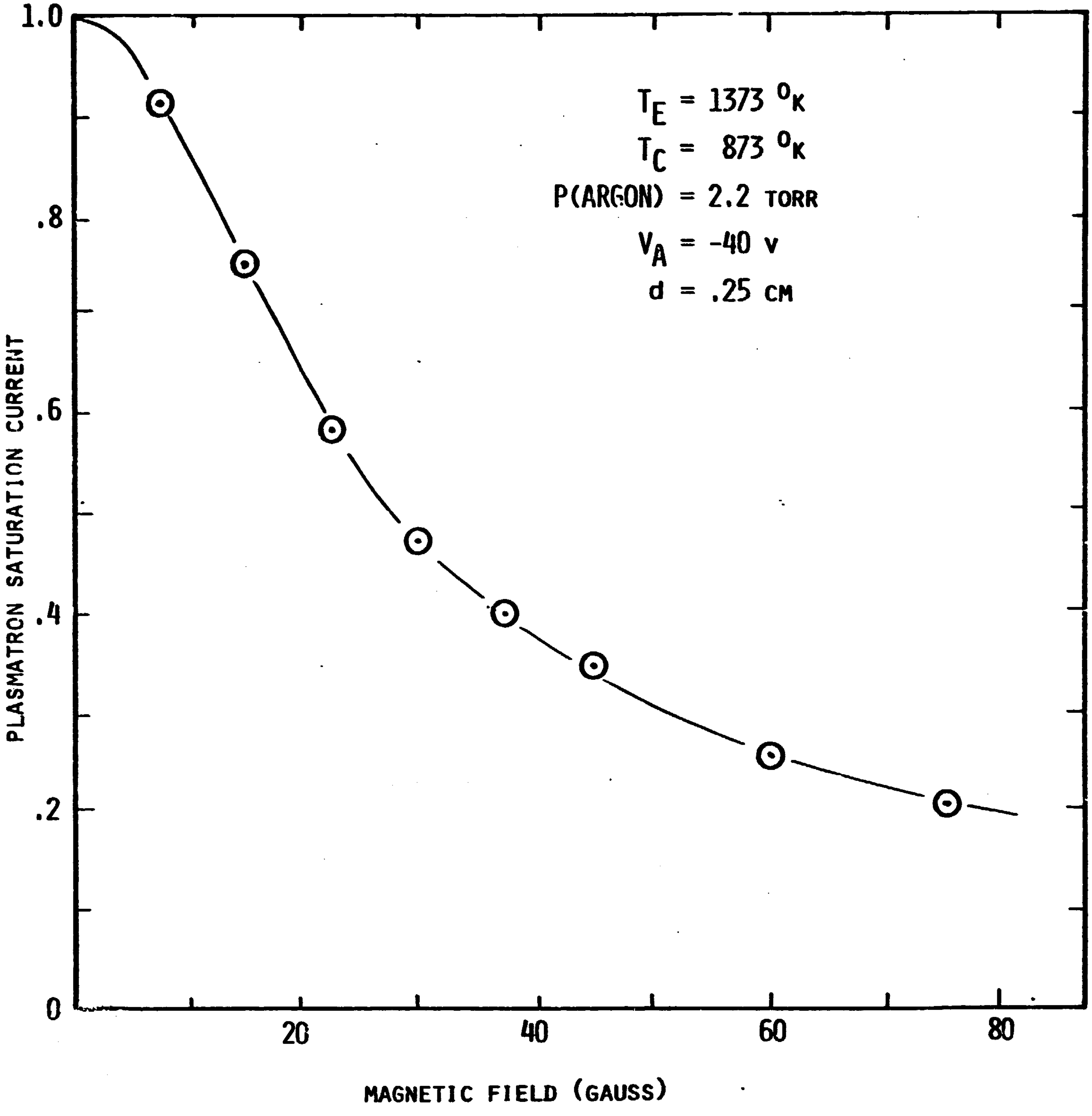

Fig. 11 Magnetic Cut-Off in the Cylindrical Plasmatron

currents this magnetic cut-off can be a serious problem. The problem can be removed, however, by appropriate design. The distributed lead discussed under Task 1900 is a promising solution to this problem.

Another magnetic effect, not so important for design optimization, is the distortion of the enhancement distribution due to J x B pumping. This is shown by the normalized distribution in Fig. 12. It is interesting to note that the distortion also allows current into the central probe.

TASK 1900 - HIGH CURRENT - ZERO POWER CONVERTER TEST

1910 - Design

ZEPO Design - Various design options for the converter, the heat source, and the heat rejection system were extensively reviewed in May.

The primary design features of the converter have been selected to approximate cell designs developed in past THX system studies performed for ERDA. For this reason a cylindrical geometry and a design current of 15,000 amperes have been selected. An emitter area of ~ 3000 cm^2 will be needed to provide this total current with the thermionic performance predicted for the converter.

More detailed design considerations included the height of the converter, its diameter, electrode material, and whether the emitter would be on the inside or outside. A central emitter was selected for several reasons: It can be used with a variety of heat sources. (Resistance heating of an external emitter would be difficult, for example.) With an internal emitter the interelectrode space grows smaller at operating temperatures, as opposed to the external emitter case where the space is almost closed when the converter is cold and opens as the emitter temperature is increased. Thus, with the internal emitter, positive spacers may be used to maintain emitter-collector concentricity, whereas this is impractical with an external emitter design. In addition, designs of both the heat rejection system and the instrumentation system are considerably simplified with an internal emitter since the colder collector is easily accessible.

Nickel was selected for both the emitter and collector. Refractories are too expensive, are difficult to join, and must be protected from an oxidizing atmosphere. Superalloys have a very high electrical resistance, requiring very thick electrodes to minimize voltage losses. As a consequence large temperature

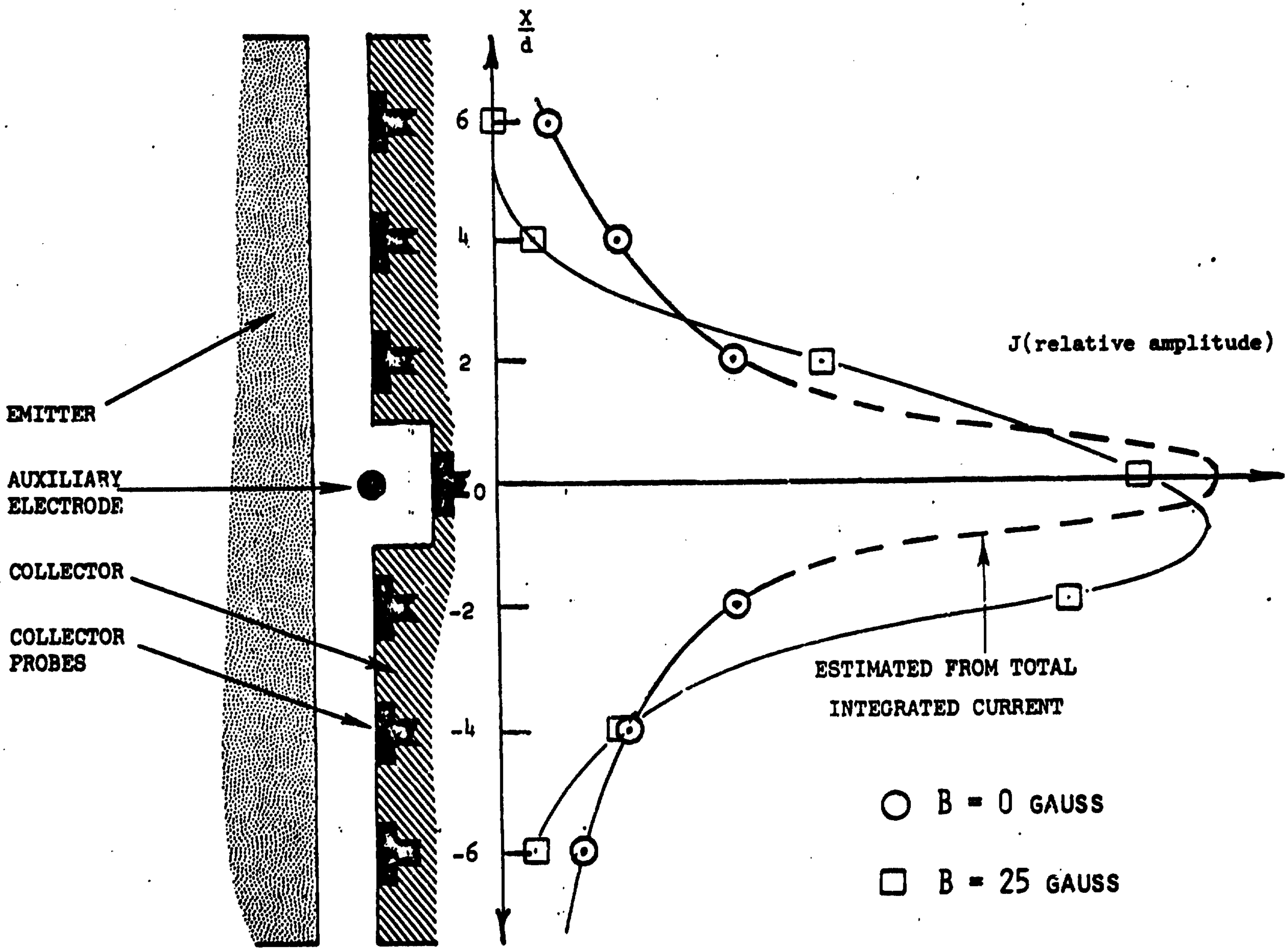

Fig. 12 Magnetic Displacement of the Enhancement Distribution in the Cylindrical Plasmatron

drops and related stresses must be incurred, limiting the performance which can be obtained.

The rough dimensions of the converter have been selected on the basis of four considerations: thermionic performance (including magnetic field affects), electrical resistance losses, temperature drops through the emitter and collector walls, and material strength considerations.

Both fossil fuel and resistance heaters were considered as heat sources. The high input powers required for the test (greater than 100 kilowatts) resulted in the selection of a gas-fired source. A resistance heater will be used as a backup heat source. The use of a heat pipe between the heat source and emitter was considered. A heat pipe would permit the use of lower heat fluxes as the heat source and would insure a uniform emitter temperature, both very attractive features. However, compatibility problems with lithium, the required working fluid, would have ruled out the use of nickel as an emitter material, and the use of refractories such as TZM or molybdenum would have overly complicated the system for these initial tests.

Five heat rejection systems were considered for cooling the collector of the converter: 1) heat transfer to high temperature steam, 2) heat transfer with a molten salt loop to an external heat exchanger, 3) heat transfer through a gas-gap to water, 4) heat transfer through metallic heat dams to water, and 5) jet impingement cooling with low temperature air. The first two alternatives significantly increase the overall system complexity and offer few compensating advantages. The third, or gas-gap heat rejection system is well-understood but suffers from two major disadvantages: It is very expensive, and it must cover the collector on the outside, thus making instrumentation of the converter very difficult. The last two approaches for the heat rejection system are currently being evaluated with laboratory tests and cost estimates.

The basic converter configuration, including the emitter, collector, current-lead region, igniter, and cesium reservoir system, is shown in Fig. 13. The heat source and heat rejection system are not shown. The igniter is an insulated probe which will be pulsed to create the first arc in the converter. This arc will propogate around the converter, "igniting" the whole interelectrode space, permitting a large current to flow.

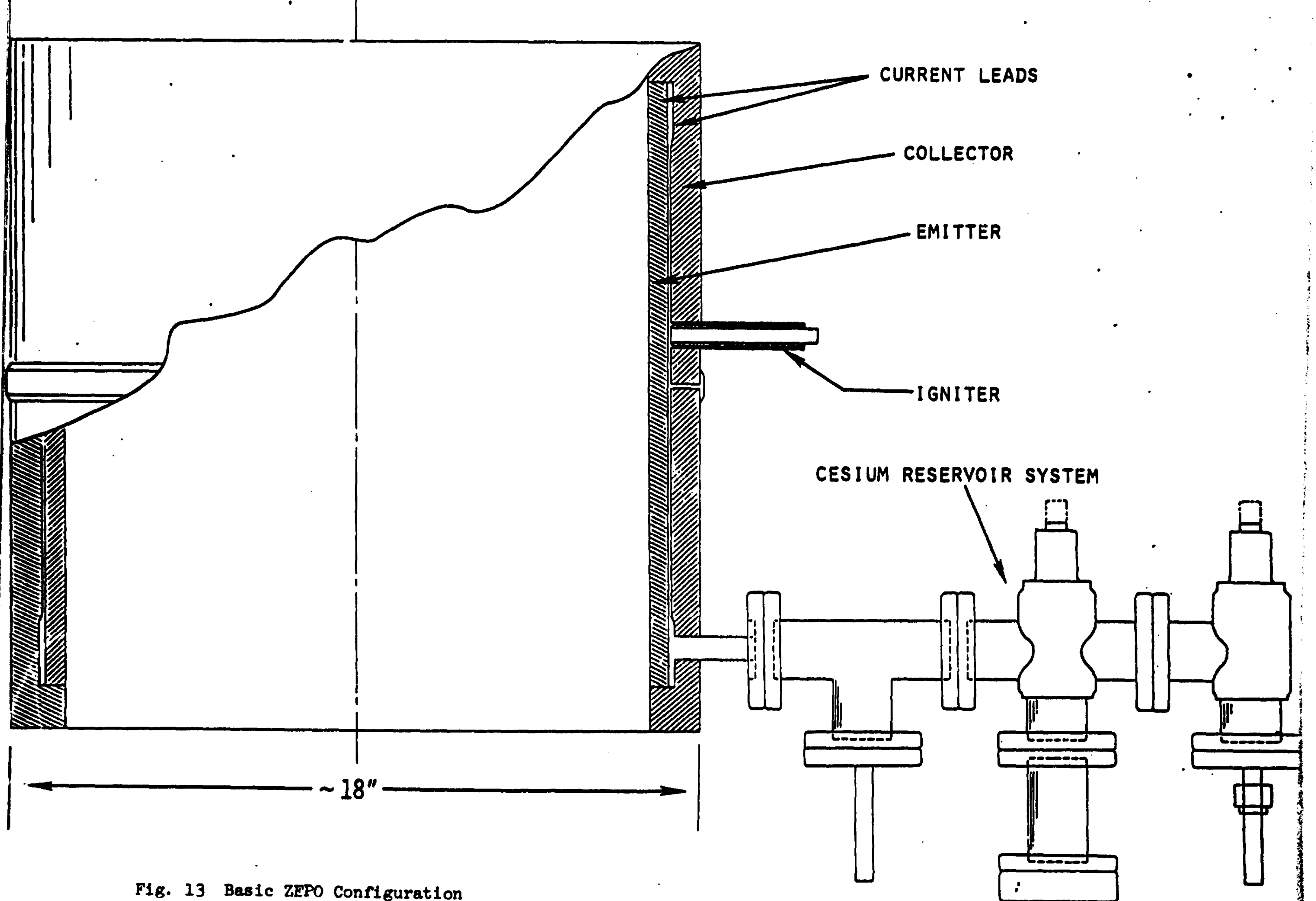

Fig. 13 Basic ZEPO Configuration

More detailed design calculations, including converter temperature, stress, are displacement profiles, will be carried out in June.

Distributed Lead Design - The high currents generated in large converters have three effects which limit converter design options: First, large currents require thick electrodes to minimize electrical losses. These electrodes are expensive, particularly at emitter temperatures where material resistances are high and refractories are needed. Second, thick electrodes result in larger temperature drops across the electrodes, giving higher peak temperatures and greater stresses. Both of these effects impose limits on the converter size and geometry. And third, a limit in converter size is imposed by magnetic fields which appear in the interelectrode space with simple concentric cylindrical electrodes. As part of the ZEPO converter design review, other possible converter configurations were devised. One concept utilizing a distributed electrode lead may substantially reduce the contraints on converter design imposed by these effects. Fig. 14 illustrates one version of the concept.

The innovation in the distributed-emitter-lead approach is the separation of the emitter from the bus bar which carries the full emitter current. This is accomplished by providing a number of small, current leads at distributed positions which carry current from the emitter, through the collector, to the colder emitter bus. Thus the distance current must flow in the emitter is only one half the distance between the small leads, rather than the full length of the converter. Consequently, the emitter may be much thinner, reducing peak system temperatures and stresses, and possibly eliminating the need for liquid metals at emitter temperatures.

The emitter bus bar operates at a low temperature, even below that of the collector. Consequently it may be made of less expensive non-refractory materials and optimized for cost and resistance characteristics.

The distributed emitter lead may also be used to maintain the interelectrode space, possibly reducing creep constraints on the emitter design.

While magnetic fields exist in the interelectrode space in the vicinity of each lead, their effects are not additive and thus do not limit the size of the converter.

The primary disadvantage in the distributed-lead approach to large converter design is the increased complexity.

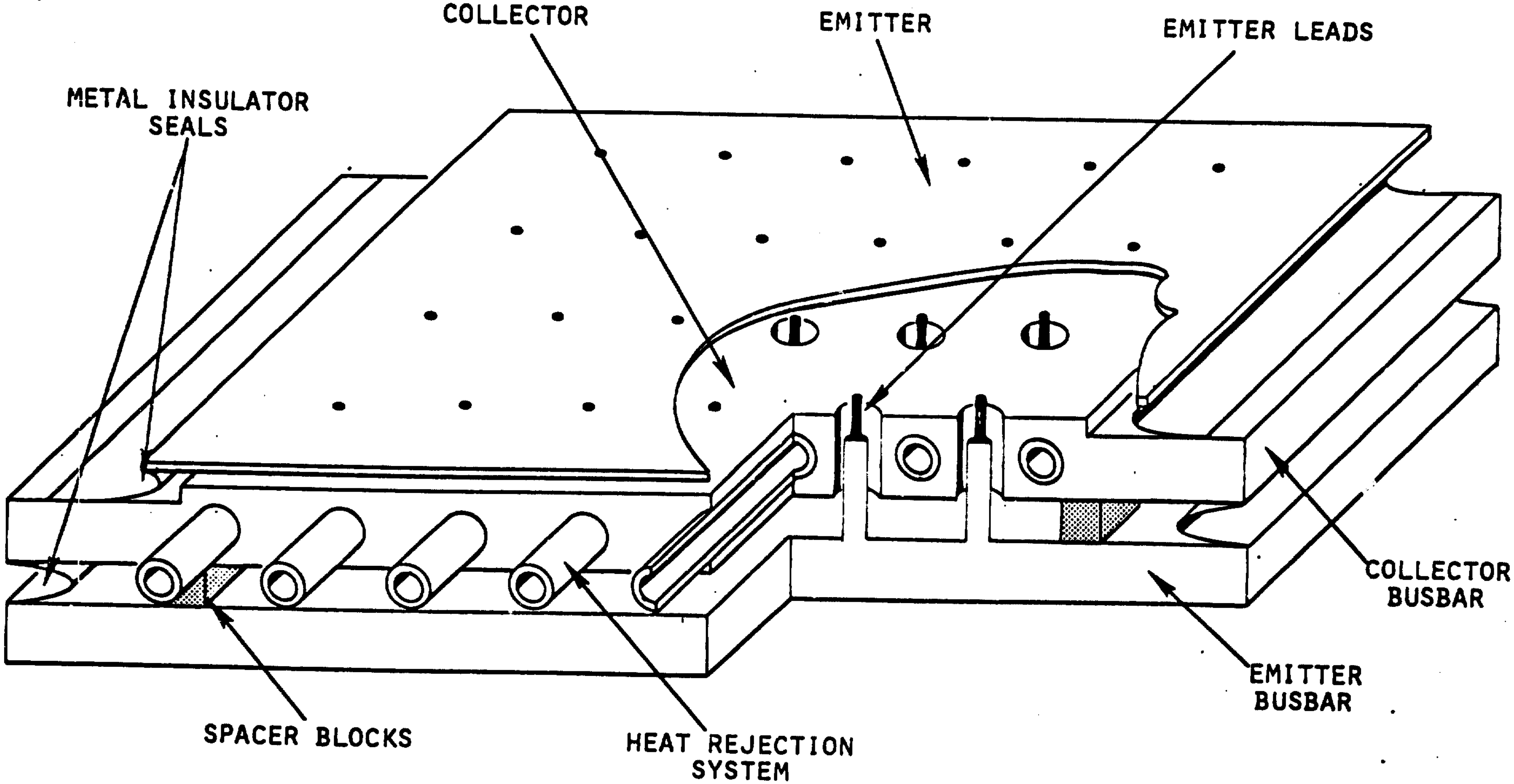

Fig. 14 One Version of a Thermionic Converter With Distributed Lead

Supporting Tests - A number of tests will be needed to support the converter design effort, particularly since the materials being used will be operating at temperatures above that where data is generally available.

During May a series of oxidation tests were conducted with Nickel 200 in a combustion environment using a mapp gas-oxygen torch. The test results confirmed the expectation that nickel has sufficient oxydation resistance for the times and temperature of interest (~ 100 hours, ~ 2300°F).

Creep tests of Nickel 200 were initiated. The early data indicates that the creep strain of nickel at 2100°F is within the limits needed for operation of the converter. Following the completion of this test further testing will be performed at higher temperatures.

The specimen designs for both tensile and thermal ratcheting tests were completed. In the thermal ratcheting tests, cylindrical nickel bodies will be subjected to temperature cycling with large radial thermal gradients. These tests are to confirm the expectation that the ratcheting strain experienced by nickel, with thermal stresses typical of those anticipating during converter operation, are within acceptable limits. These tests will begin in June.

Three types of thermionic tests are needed to support the converter design effort. The first of these, a test of magnetic field effects on converter performance, is being performed using the NASA research converter. Second, this research converter is being used to test the ignition propagation characteristics of a converter. Normally a converter is "ignited" by applying a brief initial voltage pulse (~ 2 volts) to its output terminals. Once ignited no further pulsing is needed. In the ZEPO converter it will be impractical to pulse the main electrodes. Instead a small region will be ignited, the arc will then propogate throughout the interelectrode space. The third type of thermionic test required is the performance testing of a converter with a nickel emitter and nickel collector. Nickel electrodes for a demountable converter have been fabricated and are being installed in a demountable converter for these tests.

TASK 1500 - PROJECT MANAGEMENT

Contract Modification 3-5 was added to our ERDA contract E(11-1)-2263. This modification added Task 1900, the High-Current, Zero-Power Converter Test, to the contract scope of work. New milestones, group B, are added for this additional work.

Gary Fitzpatrick and Ned Rasor visited the Foster Wheeler Corporation to begin negotiations and technical discussions leading to a system study subcontract under Task 1900. Foster Wheeler will review the THX system and associated combustion technology. They will provide a technical evaluation of a total system in which THX topping is used with the same steam system used in the thermionic topping system study performed by GE and TECO for EPRI. They will provide design and cost estimates for suitable combustors and BOP (balance of plant) for the system with THX topping. Rasor Associates will provide the THX system design and, in association with Foster Wheeler, an extended research and development plan. Negotiations for this work have been complicated by the fact that its successful accomplishment will require the investment of in-house funds by both Foster Wheeler and Rasor Associates.

A presentation for the Austin Review Meeting was prepared.

A plasma work-shop was held in conjunction with the Austin Program Review Meeting. The last half of the work-shop had to be abandoned; a severe thunderstorm prevented the participants from reassembling. A consensus report on the discussion will be circulated at a future date.

An expand , balanced program-outline was prepared and sent to Owen Merrill and John Cuttica. This proposed program outlined important areas of investigation for a broad scale effort to improve thermionic converter performance.

This section on Program Management has been included only in the copies of this report sent to ERDA-SNS, ERDA Chicago Opertaions Office, and NASA Headquarters.

ERDA CONTRACT E(11-1)-2263

ADVANCED THERMIONIC ENERGY CONVERSION

	MILESTONES FY 1975	INITIAL DATE	REVISED TARGET DATE	COMPLETION DATE
A-1	Establish criteria or "performance parameters" for comparing thermionic converter performance	10/30/75	3/30/76	3/30/76
A-2	Review converter development status to determine optimum program plan	3/30/76		3/30/76
A-3	Review system design to determine thermionic performance required for attractive utilization	5/30/76		4/30/76
A-4	Complete conceptual design study of reference THX	6/30/76		4/30/76
A-5	Operate improved converter in Mini-system to demonstrate its performance	8/30/76		
A-6	Report results of efforts to provide "Langmuir" oxygenated tungsten surface	9/30/76		
A-7	Complete annual progress report	9/30/76		
B-1	Design the thermionic heat exchanger cell, and design and specify the facility required to test the THX cell	6/15/76		
B-2	Report the description of the final design and expected performance	6/15/76		
B-3	Procurement and Assembly	9/15/76		
B-4	THX System Analysis	9/15/76		
B-5	Report results to date and a parametric test plan	9/15/76		
B-6	Achieve the primary test objective specified in Task 1930	11/15/76		
B-7	Final report to include all testing and feasibility study results as well as proposed plan for future development work	12/15/76		